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Neuropedagogy: from neurons to teaching and learning

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The article introduces Neuropedagogy - a concept that systematically integrates neuroscience, cognitive psychology, and educational theory to enhance teaching and learning. Neuropedagogy is built upon two foundational principles: (1) learning is a dynamic process of synaptic change and neural network reorganization, and (2) teachers can be considered as "neural architects" actively shaping their students' brain architecture through instruction. A novel definition of learning based on the Neuropedagogical framework is presented in this article. In addition, the article introduces the Neuroscience Informed Educational Strategies (NIES) Model - a systematic, four-stage process designed to propose a pathway for practically translating brain research findings to education and classroom practice. The four stages of the NIES model are: (1) identifying key neural principles, (2) exploring associated brain function attributes, (3) establishing pedagogical orientations, and (4) developing targeted instructional strategies. The NIES model's application is demonstrated in this article through three core neural principles: (a) the vital integration of emotion and cognition ("I feel, therefore I learn"), (b) the strengthening of synapses bonds through consistent use ("use it or lose it"), and (c) the necessity of variable periods for neural integration of new information. Teachers' reflections on the application of Neuropedagogy and the NIES model offer a promise of excellence in teaching and learning. While teacher reflections and classroom examples presented in this article attest to the Neuropedagogy and the NIES model's impact, the article underscores the need for further empirical validation and interdisciplinary collaboration to optimize and adapt these approaches across diverse educational contexts.

KEYWORDS
brain-based learning, learning theory, neuropedagogy, neuroscience-informed education, synaptic plasticity

Introduction

Brain research gained unprecedented attention in the late twentieth century, when the American Congress designated the 1990s as the "Decade of the Brain". This landmark initiative catalyzed a surge of conferences and professional development programs dedicated to the intersection of learning and neuroscience, granting educators research-based insights to strengthen teaching practice (Privitera, 2021). It was stressed that integrating neuroscience knowledge into teacher training enriches pedagogical content, and strengthens instructional efficacy (Ansari et al., 2017). The underlying rationale is that neuroscience elucidates the mechanisms of cognitive development, especially in young learners (Bear et al., 2026; Nicolelis, 2025). In their exploration of how neuroscience and pedagogy can be successfully bridged, Dubinsky et al. (2013) highlighted both the conceptual and practical connections, concluding that advances

in the neuroscience of learning -particularly neural plasticity - hold transformative potential for teacher preparation and ongoing professional growth.

Advances in neuroscience have improved the understanding of cognitive, emotional, and social processes involved in learning (La De Cruz et al., 2025). Educators worldwide increasingly appreciate the brain's central role in learning and strive to understand how neural processes influence information processing, retention, and overall academic success (Gkitoni et al., 2025). This heightened interest reflects a growing expectation that neuroscience-based knowledge can inform innovative teaching approaches and improve educational outcomes (Farmakopoulou et al., 2023; Tan and Amiel, 2019; Skourdoumbis and Row, 2025; Thomas and Arslan, 2024).

Teachers are applying findings from brain research to enhance student performance across varied domains, such as reading comprehension, language acquisition, scientific reasoning, and notably, mathematics (Antonopoulou et al., 2023), as well as in addressing developmental disorders (Bhargava and Ramadas, 2022). Educational institutions integrating neuroscience into pedagogy consistently report improvements in student achievement (Gauteaux-Betancourt et al., 2022; Schwartz et al., 2019; Tan and Amiel, 2019).

An accumulating body of evidence supports the value of neuroscience in education, reinforcing its potential as a rich conceptual foundation for teaching practice. It empowers educators with a deeper understanding of learning mechanisms and developmental variability, enabling more informed instructional decisions (Coch and Ansari, 2012; Della Sala and Anderson, 2012; Fischer and Daniel, 2009; Goswami, 2012; Ronstadt and Yellin, 2010). Empirical findings further highlight the considerable benefits of integrating neuroscience, cognitive science, and educational research to advance teacher professionalism and improve academic achievement (Brown and Daly, 2016; Hinton and Fischer, 2008; Zull, 2011). This evolving perspective exemplifies a distinct and contemporary conceptualization of teaching and learning (Tokuhama-Espinosa, 2011).

The Achva academic college eight-year program: bridging neuroscience and education through trans-disciplinary collaboration

A highly promising avenue for enhancing teaching effectiveness and learning outcomes emerged as Friedman et al. (2019) introduced an innovative approach, Neuropedagogy - fusing pedagogical expertise, cognitive psychology, and neuroscience. Neuropedagogy is grounded in the conviction that effective instruction and meaningful learning are achieved when teaching strategies align with the brain's information processing mechanisms. Its primary aim is to cultivate instructional approaches wherein neural principles directly inform educational design and practice.

Two foundational principles underpin Neuropedagogical thinking:

- *Fundamental principle 1: learning is synaptic change*. In Neuropedagogy we conceptually frame learning as involving synaptic change and reorganization of neural networks, reflected at the behavioral level in more durable knowledge, skills, and dispositions. Since learning is fundamentally synaptic (Lou, 2021), teaching, in essence, may be regarded as the facilitation of synaptic information processing. It is therefore vital for educators to understand brain-learning processes as a condition for effective instruction.
- *Fundamental principle 2: teachers are in fact "neural architects"*. Metaphorically, teachers can be viewed as "neural architects," more precisely; their instructional decisions systematically shape the patterns and strength of neural activity that underlie students' learning. Thus, educators should possess deep knowledge of how the brain receives, processes, stores, and retrieves information - a prerequisite for productive and impactful teaching.[1]

To elaborate on these principles, and to test their applicability, Friedman et al. (2019) established an eight-year transdisciplinary program at Achva Academic College, aimed at forging empirically grounded ties between brain science and educational practice. This two-semester program of elective courses that targeted practicing teachers enrolled in master's programs in educational administration, preparing them for leadership roles in early childhood, elementary, and secondary education. The participants in the eight- year program were college students who were also practicing teachers, mainly women, with 3–12 years of experience. in-service k-12 teachers and educational staff at various kindergartens and schools joined the program. Most of the students, if not all, did not have prior knowledge in biology or neuroscience; this was their first exposure to the brain and its functions. They were not requested to report on their demographic background.

Objectives and theoretical framework of the eight-year program

The program was guided by two chief objectives: first, to identify and validate best practices for bridging neuroscience with classroom teaching; and second, to demonstrate that teaching can evolve from an intuitively led art to an evidence-based discipline informed by contemporary scientific advances. Underlying the program was the premise that exposing educators to current neuroscientific knowledge and enabling its application in educational contexts would enhance instructional quality, foster academic achievement, enrich the classroom's social–emotional-cultural climate, and strengthen teacher-student-parent relationships.

The program's theoretical framework offered a novel definition of learning: *learning is a dynamic reorganization of neural network architecture in the brain, encompassing the creation and modification of synaptic links in response to experience, engagement, and sensory input. Such neural changes are manifested in the acquisition of knowledge, the shaping of beliefs, behavioral change, and students' cognitive and physical development.*

Over the course of 8 years, roughly 200 practicing teacher-participants joined the program. Systematic feedback was collected annually

1 The neural principles cited here are not intended to yield one-to-one prescriptions for classroom practice, but to serve as constraints and affordances within which psychological, pedagogical, and contextual considerations still play a decisive role. Any references to neural processes should therefore be read as conceptual grounding and heuristic guidance, not as claims that we can directly observe or measure synaptic change in everyday classroom settings.

and utilized for continuous improvement (Friedman et al., 2019). At the end of each course, participants submitted final papers describing the application of brain research in their own classrooms. Analysis of these papers yielded four core themes:

1. *Neural principles inform teaching practice*. Understanding brain structures and cognitive-emotional functions enables innovative, student-centered strategies. Teachers can leverage neuroscience to tailor and adapt instruction to individual needs.
2. *Neuroscience validates professional practice*. Brain research offers scientific validation of teachers' existing practices, bolstering professional confidence and grounding instructional decisions in empirical evidence.
3. *Neuroscience initiates new professional pathways*. Familiarity with neuroscience enriches pedagogical thinking and fosters new approaches for diverse learners.
4. *Neuroscience enhances teacher-student relationships*. Understanding the neural basis of student behavior helps teachers develop more responsive and effective approaches, deepening connections and relationships with students.

In the program's seventh year, a comprehensive follow-up study surveyed all cohorts of program graduates; questionnaires containing open-ended items garnered 2 main retrospective reflections:

1. *Validation of prior knowledge*. Participants widely noted that the program confirmed and provided scientific underpinning for their intuitive practices: "I learned that methods I had used intuitively were consistent with brain research". "The program validated my approach, my teaching instincts proved sound when supported by neuroscience".
2. *Acquisition of novel knowledge*. The program offered fresh perspectives on brain function and pedagogy: "I gained an alternative perspective on learning processes, for both my students and my own children". "Neuroscientific explanations greatly enhanced my understanding of teaching and life".

Respondents also reported substantive changes in lesson planning and instructional delivery: "The program influenced both my goal-setting and planning processes". "I now interpret student behaviors through a neural lens". "I have integrated numerous principles from the course into my teaching". "Since learning Neuropedagogy, these concepts inform all aspects of my work".

Neuropedagogy advocates a transdisciplinary paradigm, bridging cognitive psychology, and educational theory. It maintains that equipping teachers with up-to-date knowledge of brain function, and facilitating the integrating of this knowledge into teaching and relational practice, can significantly elevate instructional quality and student achievement. This perspective aims to contribute to a more science-informed conception of teaching, rooted in cutting-edge empirical research.

Purpose

The purpose of this article is to propose a theoretical model of applied Neuropedagogy to the search for effective teaching and learning strategies, named the Neuroscience Informed Educational Strategies (NIES) Model for teaching and learning. The model derives conceptually from the insights gained by the Eight-Year Program: Bridging Neuroscience and Education through Trans-Disciplinary Collaboration. We introduce here the NIES model and three examples of utilizing it for productive educational practices in the classroom and the school settings, as grounds for future empirical validation.

The neuroscience-informed educational strategies model

The Neuroscience-Informed Educational Strategies (NIES) model provides a structured conceptual framework for translating findings from neuroscience into educational practice. It consists of four sequential phases: (1) identifying relevant neural principles that underlie cognitive and learning processes; (2) identifying corresponding brain function attributes; (3) establishing pedagogical orientations; and (4) developing specific instructional strategies. Figure 1 presents the systematic transition from neuroscientific mechanisms to practical pedagogical applications.

Stage 1: identifying relevant neural principles

The initial stage focuses on selecting neural principles that are theoretically relevant to cognition and learning. Since information processing in the brain occurs through diverse mechanisms - some well-established, others still being explored - effective teaching practices should be aligned with these underlying biological principles.

Representative neural principles include the following:

- Synaptic plasticity as the foundation of brain function
- Learning as a process of modifying synaptic connections
- Repetition as a mechanism for forming long-term memory
- Temporal dependency in neural information integration
- Hierarchical organization of learning processes
- Reliance of new learning on preexisting neural structures
- Influence of embedded memories on new stimuli
- Analogical reasoning through comparison and contrast mechanisms
- Integration of cognitive and emotional systems in learning

Stage 2: identifying brain function attributes

The second stage connects neuroscientific principles to observable cognitive and behavioral phenomena by identifying the specific brain attributes that operationalize the selected neural principles. These attributes explain *how* the brain implements the underlying neural mechanisms.

Example 1: *Synaptic Plasticity as the Foundation of Brain Function*
Brain function attributes related to this principle include the following (Citri and Malenka, 2008; Martin et al., 2000):

1. *Learning and memory*: Modifications in synaptic strength facilitate memory formation and selective forgetting, primarily through processes such as long-term potentiation (LTP) and long-term depression (LTD).
2. *Neural flexibility across the lifespan*: Neuroplasticity mechanisms enable learning of new languages and skills and are

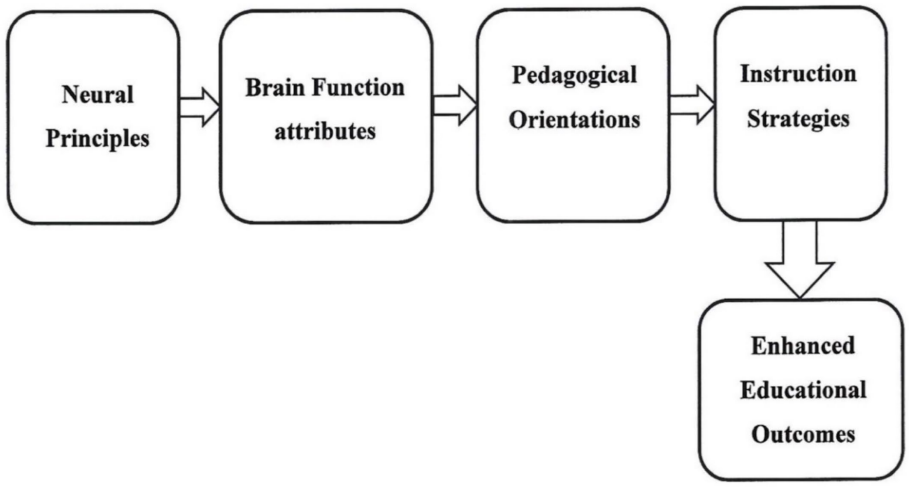


FIGURE 1
The neuroscience informed educational strategies (NIES) model.

integral to recovery from injury. Although more pronounced in early development, they persist across the lifespan.
3. *Adaptation to environmental change*: Neural patterns are continuously updated by experiential feedback.
4. *Dependence on practice*: Synaptic alterations require consistent repetition for consolidation and retention.
5. *Connection to sleep*: Sleep, particularly REM and slow-wave phases, stabilizes synaptic change and supports long-term memory.

Example 2: *New Information Processing Relies on Existing Neural Repositories* Key attributes include (van Kesteren et al., 2012; Bein et al., 2014):

1. *Schema activation*: Existing mental frameworks facilitate the assimilation and interpretation of new information.
2. *Associative learning*: The brain links new stimuli to previously stored information by strengthening relevant neural networks.
3. *Top-down processing*: Prior experiences shape perception and attention.
4. *Contextual learning dependency*: Absence of prior schemas increases cognitive effort and processing time.
5. *Parallel and sequential processing*: The integration of new data involves simultaneous multimodal processing and analytic reasoning.

Stage 3: establishing pedagogical orientations

Stage 3 translates neuroscientific principles into actionable pedagogical orientations. The aim is to formalize how brain-based attributes guide effective instructional planning. Drawing on the neural principle of synaptic plasticity, the following pedagogical orientations can be derived:

1. Spaced and gradual learning: Distributed practice enhances retention more effectively than massed rehearsal. Lessons should be sequenced to revisit prior material at regular intervals, supported by short formative assessments.
2. Active engagement: Multimodal, interactive approaches such as problem-based learning (PBL), group dialogue, and creative design tasks activate multiple neural systems and strengthen memory encoding.
3. Adaptive challenge level: Learning tasks should be optimized within the student's zone of proximal development, balancing cognitive demand with achievable progress.
4. Rest and sleep integration: Adequate downtime and sleep should be emphasized as essential for synaptic stabilization and memory retrieval.

Stage 4: developing instructional strategies

The final stage focuses on designing specific instructional tools and techniques derived from the pedagogical implications of the neural principles. For synaptic plasticity, the following instructional practices are recommended:

- *Spaced repetition*: Systematic review sessions scheduled over time
- *Active retrieval*: Use of quizzes, reflective summaries, and student-led questioning
- *Interleaved practice*: Integration of varied problem types to encourage flexible application of knowledge
- *Guided reflection*: Promoting awareness of individual learning processes and metacognitive monitoring
- *Structured cognitive rest*: Incorporation of short, intentional breaks to facilitate consolidation and prevent fatigue.

The NIES model in practice

The NIES model is a practical tool to guide teachers, educators, and curriculum developers in designing educational strategies. To demonstrate its application, we focus on three neural principles underpinning potent teaching and learning processes: A. Emotion and Cognition intertwined. Neural principle B: Consistent, coordinated and increased use of synapses strengthens them, and lack of use is conducive to synapse degeneration ("use it or lose it"), and C. New information requires neural integration; creating changes in existing or new synaptic connections necessitates variable periods.

Neural principle A: emotion and cognition intertwined

Building on Antonio Damasio's work, Immordino-Yang (2016) proposed that emotion serves as the foundation or platform for learning, decision-making, creativity, and social functioning. She characterized the relationship between emotion and cognition as "emotional thought" and coined the powerful expression: "I feel, therefore I learn". Based on this framework, she argued that teachers would benefit from recognizing the importance of their students' emotions; failure to do so will result in losing the ability to engage students in learning, since emotion constitutes the primary driver of the learning process. Supporting this, Jaak Panksepp's research on Basic Emotion Command Systems highlights that human behavior arises from core emotional systems, particularly the "Seeking" and "Play" systems (Panksepp and Biven, 2012). The Seeking system, variously termed the reward, curiosity, or interest system, generates enthusiasm, intrinsic motivation, and the pursuit of meaning (Panksepp, 1998, p. 14). Seeking may facilitate powerful intrinsic reward from the very act of seeking itself. Consequently, the Seeking system can serve intrinsic motivation - pursuing novelty, challenge, and capacity building for its own sake - fuels self-directed exploration and learning (Ryan and Deci, 2000). The Play system addresses the need for social connection and joy in learning. Classroom play is essential in early childhood, supporting cognitive and social growth. Periods of play foster renewed focus and engagement with academic material.

Figure 2 visually represent the relationship between the neural principle whereby emotion and cognition constitute a unified functional unit, anchored in the brain's anatomical structure and physiology. For example, the limbic system in the brain maintains multi-layered connections with the cerebral cortex, creating both direct and indirect pathways for emotional-cognitive information processing. The primary pedagogical implication is clear: optimal learning occurs where content, environment, and instruction evoke positive emotional states. Key strategies for harnessing this principle include: Illuminating the emotional resonance of learning content, Integrating play as an instructional medium, and Cultivating curiosity, wonder, and intrinsic motivation, especially through challenge, novelty, and collaborative work. Illuminating emotional dimensions of learning, incorporating play as a crucial tool for encouraging learning and creating enjoyable learning environments that promote collaborative work, and most importantly fostering the emotion of seeking and curiosity, forms the foundation for developing and nurturing intrinsic motivation (see Figure 2).

Teacher implementation examples

The teacher reflections and classroom vignettes presented in this article are illustrative narratives, derived from final course papers and retrospective questionnaires. They were not collected within a pre-registered, hypothesis-driven research design. They were analyzed using systematic qualitative methods (e.g., coding frameworks, inter-rater reliability). These teacher examples illustrate practices inspired by Neuropedagogical principles; they do not provide direct evidence of underlying neural changes; these accounts should be understood as practice-based exemplars that illuminate how Neuropedagogical ideas and the NIES model can be interpreted and applied by teachers in authentic contexts. They offer face-valid, experience-near illustrations

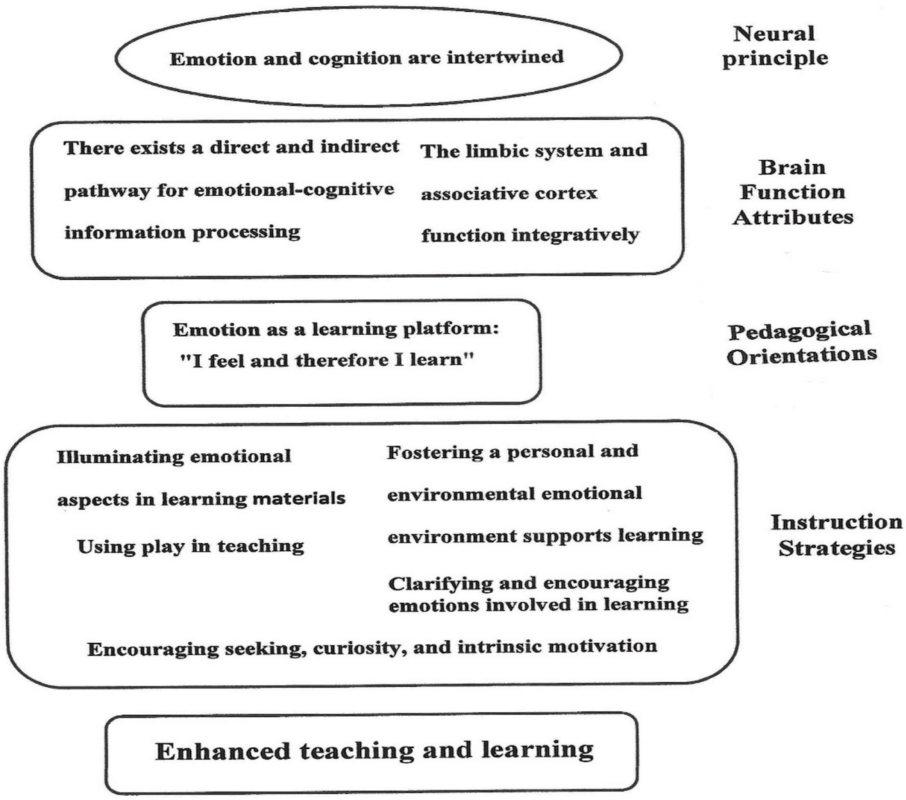


FIGURE 2
Integrating cognition and emotion may facilitate enhanced teaching and learning.

of how participants perceived and translated the proposed neural principles into their own classroom practice.

Managing stress to support learning: "*When I observe a student anxious about tests, vaccinations, or social dynamics, I bring them to our 'empowerment room' equipped with beanbags and games. Through play and conversation, students decompress and become ready to learn*".

Play-based kindergarten teaching: "*In kindergarten, most of the teaching is through visual means and especially play. Through play, the child learns to recognize different properties of objects and materials and to operate them. Through play, the child learns to compare, distinguish, and develop the ability to compare, distinguish, sort, generalize, and draw conclusions. In kindergarten teaching, I mainly use songs, recitations, dance, movement, games, with the aim of creating positive experiences and enjoyment. These lead to creating interest, curiosity, and cooperation on the part of the learner. The basic assumption for meaningful learning (from what we learned in the course) is that the more experiential the teaching is for students, the stronger signals it may facilitate in the students, and the greater the chance that these signals will create long-term memory*".

Experiential geography learning: "*When teaching directions and the compass rose, I used a 'treasure hunt' game. Students navigated using directional clues, engaging multiple senses and movement. In follow-up lessons, they designed their own games, reinforcing knowledge through creative application*".

Teachers equipped with neuroscience knowledge report on enhanced professional confidence, improved student relationships, and greater job satisfaction. This scientific grounding strengthens pedagogical mastery, facilitates sound decision-making, and cultivates both patience and empathy. The implementation examples above illustrate how neuroscience-based strategies, such as temporally structured learning and active engagement, translate into richer, more effective educational outcomes.

Neural principle B: consistent, coordinated and increased use of synapses strengthens them, and lack of use is conducive to their degeneration ("use it or lose it")

Neural activity generated by learning, experience, or practice fortifies connections between nerve cells, fosters the creation of pathways, and synapses (Abbott et al., 2021). However, not all newly formed synaptic connections endure; only those exercised through consistent and coordinated use are preserved, while connections lacking activity deteriorate and may vanish (Shadlen and Kandel, 2021; Amaral, 2021). This phenomenon familiarly termed "use it or lose it" is a central tenet in neuroscience-informed teaching.[2]

Donald O. Hebb articulated a foundational hypothesis regarding synaptic transmission, strengthening, and decay: "*When an axon of cell A is near enough to excite a cell B, and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased. When one cell repeatedly assists in firing another, the axon of the first cell develops synaptic knobs (or enlarges them if they already exist) in contact with the soma of the second cell*" (Hebb, 1949, pp. 62–63).

This principle, known as Hebb's Rule, states: "Cells that fire together wire together" describes how nerve cells in close proximity that communicate in a coordinated manner develop strengthened connections that become more robust over time. These interconnected synapses are termed "Hebbian Synapses." coordinated communication between neurons progressively strengthens their synaptic bonds, resulting in robust neural networks ("Hebbian synapses"). Conversely, a lack of synchronous activity precipitates weakening and potential elimination of connections.

Although initially unconfirmed by direct empirical evidence, Hebb's rule became the focal point for subsequent research validating these processes. Since the 1990s, advancements in brain imaging have further illuminated Hebbian learning and its neural substrates, notably spike-timing-dependent plasticity (STDP): electrical patterns thought to underlie learning, memory, and sensory perception (Andrade-Talavera et al., 2023). The upshot is clear: repeated, sustained activation transforms transient synaptic links into enduring networks, while inactivity breeds degeneration.

Learning fundamentally shapes synaptic strength, efficient communication, the emergence of new neural networks, and the reinforcement of existing brain circuits all depend upon synaptic flexibility. Absent this adaptability, learning-memory formation, retention, and cognitive development-is impossible. If memory resides in the weight and distribution of synaptic connections, then learning is the process of creating new connections and recalibrating their strength through experience (Lou, 2021, pp. 448–490).

Figure 3 illustrates this process: increased synaptic activity consolidates connections, establishing stable communication, while inactivity precipitates synaptic loss. This insight anchors Neuropedagogy, guiding educators to design teaching strategies that engineer robust neural networks in learners' brains. The pedagogical implications are immediate (see Figure 3):

- From a Neuropedagogical perspective, it is advisable that teaching prioritize the construction and reinforcement of synaptic networks.
- Repetition, systematic, meaningful review of material, is vital for crystallizing long-term memory and deepening comprehension.
- Instructional approaches should integrate memorization and practice, engaging multiple sensory modalities.

The *Neural Principle* in Figure 3 ("use it or lose it") points to the *Brain Function Attributes*: cells that wire together wire together; nerve cells with increased shared activity strengthen ad stabilize their connections; inactive synaptic connections degenerate. The *Pedagogical Orientations* may be, for example: teaching that involves influencing the formation of new synaptic connections and strengthening existing ones; repetition of learned material to crystalize long-term memory, learning, and learning-materials comprehension. The *Instruction Strategies* are, for example, repeated instruction of topics as a fundamental teaching component, teaching based on memorization and practice, to establish stable synaptic connections, engagement of multiple brain sensory areas.

2 In practical terms, this implies that frequent, coordinated activation of specific neural pathways increases the probability of long-term strengthening of those pathways, whereas prolonged inactivity is associated with weakening of connections.

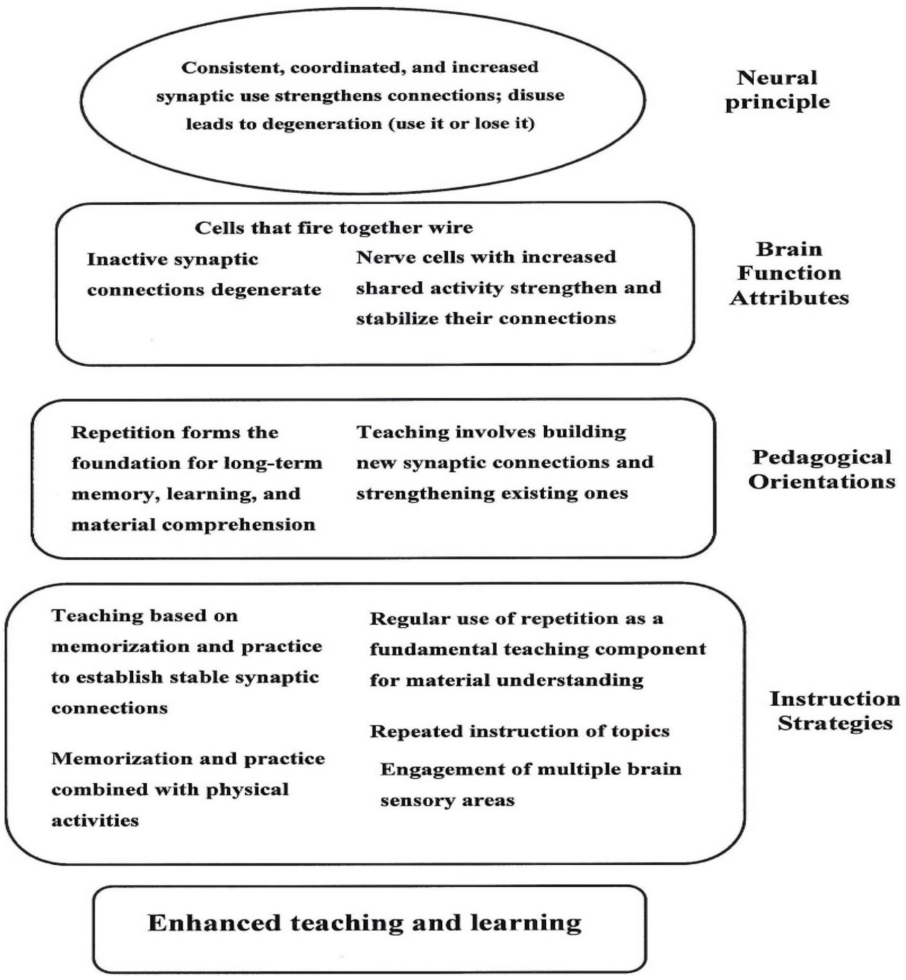


FIGURE 3
Consistent and increased activity between neurons and its contribution to enhanced teaching and learning.

Teacher implementation examples

Memory and repetition

"*When learning new material to achieve long-term memory, simply absorbing the content is insufficient; the material must be retrieved repeatedly. Learning, training, practice, and repetition result in synaptic addition and reorganization at neural connection sites, creating new connections that previously did not exist. This suggests that repeated study of material leads to long-term memory retention. Even when neural connections are inconsistent or occur after delays, the speed and efficiency of renewal will be superior to establishing entirely new synaptic connections*".

Meaningful repetition

"*Memorizing new information is crucial for memory formation. Learning something new requires repetition in various forms. Memorizing and repeatedly reviewing new material is most effective when combined with comprehension and personal relevance for the student. The importance of repetition for learning and memory retention has become increasingly clear to us. We understand that frequent classroom repetition of study content in close succession helps students recognize the material's importance and retain its long-term. We recognize that persistence and multiple repetitions enhance learning capabilities*".

Neural principle C: information integration requires variable time, new knowledge demands time for neural consolidation

New neural communication pathways emerge when existing neural axons undergo elongation processes, ultimately developing into terminals capable of forming synapses with other neurons. Axonal elongation and progression occur incrementally, advancing segment by segment. Growth cones positioned at axonal terminals serve as guidance mechanisms, directing axons toward their target destinations. Upon reaching target destinations, axons seek appropriate synaptic partners within their local environment for communication establishment (Sanes, 2021). Neural connections and interactions, ranging from simple to complex, operate across temporal dimensions spanning milliseconds to several months, encompassing both brief and extended periods (Nicholls et al., 2021). The fundamental principle that new information requires time for neural integration is central to educational planning and learning design (Bear et al., 2026; Sanes, 2021).

Figure 4 illustrates the relationship between the principle stating that new information absorption may facilitate novel synaptic connections and the temporal requirements for connection formation. The process of establishing new connections begins when neurons extend axons to connect with other neurons—a process that may range from milliseconds to weeks or months. The pedagogical implications suggest that temporal intervals are necessary for information absorption and integration, which can be strategically utilized for various classroom purposes. This approach involves teaching discrete learning units with appropriate content and temporal spacing, incorporating mindfulness practices, physical activity, or other creative activities during temporal intervals. Notably, concentrated and accelerated learning formats may fail to achieve their intended educational objectives. The pedagogical implications are immediate (see Figure 4):

- New material acquisition requires sufficient time for neural integration.
- Effective instruction should segment complex content into manageable units punctuated by "spaced" breaks.
- Challenging material necessitates longer integration periods for true mastery, shortcuts generally undermine deep learning.
- Spaced learning is more effective than massed, intensive instruction.
- Extended, distributed courses support better absorption and recall compared to compressed formats.
- Ample timeframes allow for richer practice, rehearsal, and review.

Teacher implementation examples

Avoiding instructional rush

When learning content is compressed into short time units, or when instruction moves rapidly from one topic to another, minimal information is retained in students' memory. I definitively learned this remarkable principle this year. As a novice teacher, I felt compelled to "rush" through learning material to prepare students for examinations. However, following my exposure to neuropedagogical principles, I understood the importance of pacing instruction appropriately and recognizing that the brain absorbs specific amounts of information within particular memory ranges. Students should never be pressured or overwhelmed with excessive learning material; as such, material will not be consolidated into long-term memory. This understanding helped me avoid instructional failures.

Structured temporal design

"*When introducing new material, I structure learning units into multiple segments with strategic breaks to maintain engagement and prevent cognitive fatigue. In the initial segment, I present content through diverse modalities including presentations, readings, and lectures. The second segment incorporates practice activities requiring retrieval of information from the first segment. The third segment involves comprehension and application tasks. Between segments, I integrate brief intervals of several minutes featuring kinesthetic activities,*

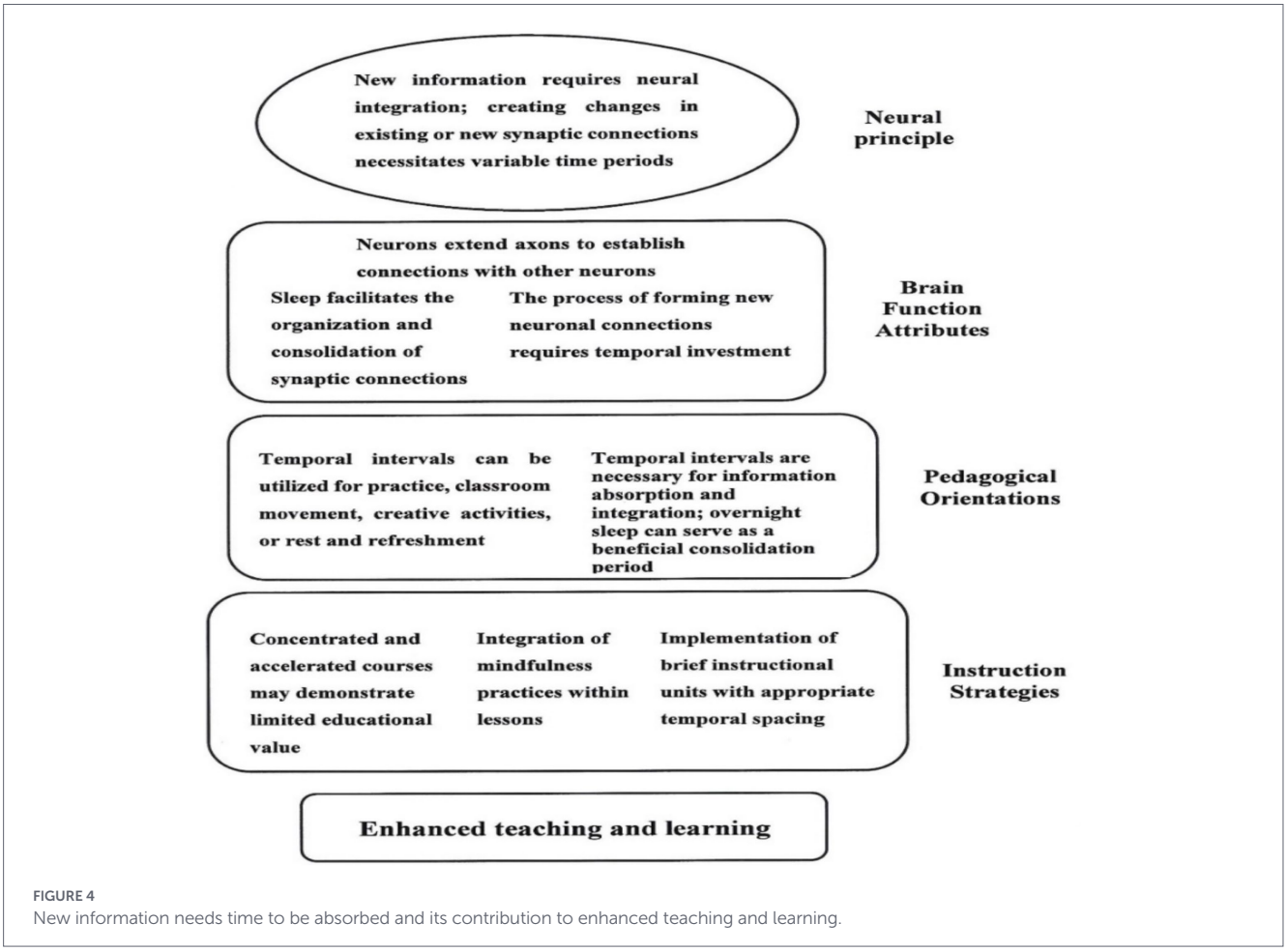


FIGURE 4
New information needs time to be absorbed and its contribution to enhanced teaching and learning.

games, or creative work such as clay modeling, all thematically connected to the learning content. This pedagogical approach aims to create spaced repetition at 10–15 min intervals, ensuring optimal absorption and consolidation of new information into long-term memory. This method consistent with highly effective for establishing foundational knowledge, facts, concepts, and definitions, while emphasizing retrieval practice and meaningful conceptual connections. Furthermore, this instructional framework allocates increased time for independent and active learning experiences that promote higher-order thinking skills including comprehension, inference, analysis, and application. Such learning experiences can enhance student motivation through curiosity, engagement, and demonstrated efficacy".

The-distinctiveness of neuropedagogy and of the NIES model in relation to existing frameworks: positioning neuropedagogy within critical discussions in educational neuroscience

While Neuropedagogy relates to fields such as educational neuroscience, mind–brain education, and brain-based learning, it is conceptually and methodologically distinct from them. Educational neuroscience is primarily a research field that investigates the neural bases of learning and cognition, and only secondarily suggests implications for practice; its center of gravity lies in the laboratory and in basic science. Mind–brain education and brain-based learning seek to translate neuroscientific insights into educational discourse and classroom recommendations, but they often remain at the level of general principles or lists of "brain-informed" strategies and do not usually provide a systematic procedure for moving from specific neural mechanisms to concrete instructional design. In contrast, Neuropedagogy, as proposed in this article, is primarily a pedagogical framework. It defines learning explicitly as dynamic synaptic reorganization, conceptualizes teachers as "neural architects," and operationalizes this stance through the four-stage NIES model, which requires educators to (1) identify precise neural principles, (2) specify corresponding brain function attributes, (3) derive pedagogical orientations, and only then (4) design targeted instructional strategies. In this sense, Neuropedagogy is not merely "neuroscience applied to education," but a normative, practice-oriented pedagogy whose units of analysis, core concepts, and design process are anchored explicitly in contemporary knowledge about neural information processing and plasticity, while remaining accountable to educational aims, classroom realities, and teacher professional judgment.

The NIES model's conceptual distinctiveness comes from three main features: (1) its starting point in explicit neural principles,(2) its obligatory four-stage translation sequence, and (3) its normative demand that every instructional choice be justified both pedagogically *and* neurobiologically. Existing "brain-based" or mind–brain-education models usually share some of these elements, but not all in a single, tightly coupled framework.

Starting point: explicit neural principles, not generic "brain facts"

Most existing approaches (educational neuroscience, brain-based learning, MBE) work in practice with broad ideas such as "the brain is plastic", "emotions matter", or "multi-sensory learning is beneficial". The NIES model requires that teachers begin from clearly specified neural principles (e.g., synaptic plasticity, temporal dependence of integration, reliance on prior networks) and treat them as the *formal input* to the design process. In other words, the unit of analysis is an articulated neural mechanism, not a general slogan about the brain.

Structured four-stage translation path

Many frameworks offer lists of "brain-informed strategies", but often the path from mechanism to practice is implicit or ad-hoc. NIES is conceptually distinct in that it defines a fixed, hierarchical mapping. That is, teachers are not invited simply to "use neuroscience", but to walk through a mandatory chain of reasoning: from mechanism → attribute → orientation → strategy. This explicit grammar of translation is what differentiates NIES from more descriptive models that only say, "Neuroscience can inform teaching" without specifying how.

Dual accountability: to the brain and to pedagogy

Some existing models lean heavily on neuroscience (risking neuromyths or over-interpretation); others stay mainly pedagogical and sprinkle in brain terminology. NIES is defined as a neuropedagogical framework: Each pedagogical orientation must be justifiable in terms of both neural affordances (e.g., consolidation windows, necessity of repetition, emotion–cognition coupling). Educational aims (meaningful learning, equity, motivation, classroom realities). Conceptually, this means that the NIES does not treat neuroscience as an "add-on" to good teaching, but as a co-equal, structuring dimension of pedagogical reasoning.

From descriptive translation to design methodology

Many mind–brain-education or brain-based learning accounts describe how existing findings *could* be applied; NIES instead proposes a *design methodology* a repeatable procedure that any teacher can use to generate new strategies from changing scientific knowledge. Conceptually, this shifts the focus from "cataloguing what the brain suggests" to engineering instruction as an ongoing design science grounded in neural principles.

Discussion

The article introduced Neuropedagogy as an innovative theoretical framework integrating neuroscience with cognitive psychology and educational theory and practice. The principal contribution of this article is the Neuroscience Informed Educational Strategies (NIES) Model. The model offers a systematic four-stage framework for adapting neuroscientific findings to educational practice: (1) identifying relevant neural principles, (2) focusing on brain function attributes related to these principles, (3) establishing appropriate pedagogical orientations, and (4) developing specific instructional strategies. The article demonstrated the model's application through three fundamental neurological principles: (a) emotion-cognition integration, (b) synaptic strengthening through consistent use ("use it or lose it"), and (c) the temporal requirements for neural integration of new information. Currently, the assessment of the NIES model rests primarily on qualitative reports and retrospective feedback of its users. Future empirical validation and longitudinal comprehensive studies will add to the model's validity.

The article highlights four key contributions of neuropedagogy:

1. *Enhanced teaching practices*: The NIES model enables educators to tailor instruction to the brain's information processing. The examples presented in this article include innovative strategies such as geographic treasure hunts, "empowerment rooms" to relieve student stress, and lesson designs based on neuroscientific principles.
2. *Enhanced student learning outcomes*: Understanding brain-based learning processes allows for research-driven practices - meaningful repetition, play-based instruction, and strategically structured time for learning - that match natural neural rhythms and enhance achievement.
3. *Professional validation and development*: The neuropedagogical framework offers scientific validation for existing effective teaching practices, fosters confidence, and opens new avenues for professional growth. Teachers report greater job satisfaction and pedagogic mastery.
4. *Enhanced teacher-student*: Neuroscientific insights into student behavior empower educators to design more nuanced approaches, enhancing empathy, patience, and improved inter-personal relations.

Implication for educational practice

The *NIES* model offers three important implications for educational practitioners and policymakers:

1. *Teacher training*: Systematically integrating neuroscience into pre-service and in-service teacher education is essential.
2. *Curriculum design*: Curricula should reflect neural mechanisms by spacing content, engaging emotions, and accounting for individual learning tempos.
3. *Assessment*: Evaluations would benefit from prioritizing meaningful consolidation and measured mastery rather than rapid information delivery.

Neuropedagogy and the NIES model mark a substantive leap in educational science, embedding teaching and learning in a neurobiological framework. By recognizing learning as a process of dynamic synaptic change, this approach drives a paradigmatic shift toward science-informed practice. The interdisciplinary integration of neuroscience and education reveals pathways for understanding learning mechanisms and constructing effective strategies. However, full realization depends on continued research, targeted professional development, and ongoing dialogue between scientific and educational communities. Neuropedagogy thus promises a transformative future in which teaching and learning are deeply consonant with the inherent operations of the human brain, supporting the pursuit of evidence-based educational excellence worldwide. The successful implementation of these principles demands persistent scholarly engagement, robust teacher training, and interdisciplinary collaboration.

Beyond its contributions, the present work would rather be situated within the broader debate on the promises and limits of educational neuroscience. A substantial literature has documented the persistence of educational neuromyths–oversimplified or incorrect claims about the brain and learning - and has shown how such misconceptions can foster ineffective "brain-based" practices in schools. In parallel, influential commentators have argued that building a direct, prescriptive bridge from basic neuroscience to classroom instruction may be a "bridge too far", given the gap between neural and behavioral levels of analysis and the fact that psychological constructs are often more proximal to educational practice. Additional work has highlighted the translation gap between researchers and teachers, noting that differences in language, training and goals, together with low-quality popularization, contribute to misunderstandings and unrealistic expectations of what neuroscience can offer to education.

Neuropedagogy and the NIES model should therefore not be read as a simple solution to these concerns, but rather as an attempt to respond to them in a disciplined way. By requiring an explicit, multi-stage pathway from clearly specified neural principles, through brain function attributes, to pedagogical orientations and only then to instructional strategies. The model aims to reduce susceptibility to neuromyths, to respect level-of-analysis constraints by integrating rather than replacing psychological and pedagogical constructs, and to narrow the translation gap by offering teachers a transparent reasoning framework instead of decontextualized "brain facts." In this sense, the framework is as much a proposal for how *not* to use neuroscience in education, as it is a proposal for how to do so. Future empirical work will be crucial to examine not only the effectiveness of NIES-based instruction, but also the extent to which this structured approach indeed mitigates some of the conceptual and practical problems identified in the critical literature.

Limitations and future research directions

The growing literature on educational neuroscience has raised important critical perspectives that this article explicitly acknowledges. First, a substantial body of work has documented the persistence and potential harm of educational neuromyth–oversimplified or incorrect claims about the brain and learning (for example, "learning styles," "10% of the brain", rigid "left-brain/right-brain" typologies), and has warned that such misconceptions can lead to ineffective or even detrimental "brain-based" practices in schools. For a review of neuromyths busting in education see Whitman and Kelleher (2016), pp. 36–39. Second, several authors have argued that attempts to build a direct, prescriptive bridge from basic neuroscience to classroom instruction may be a "bridge too far", because of the gap between levels of analysis (neural vs. behavioral) and because, in many cases, psychological and pedagogical constructs are closer to educational practice than brain data per se. Third, commentators have highlighted the translation gap between scientists and teachers: limited mutual training, differences in language and goals, and low-quality popularizations have all been shown to contribute to misunderstandings and unrealistic expectations about what neuroscience can offer to education.

Within this critical context, Neuropedagogy and the NIES model are not proposed as a "shortcut" that bypasses these concerns, but as a *discipline-building response* to them. By requiring an explicit, multi-stage pathway from clearly specified neural principles, through brain

function attributes, to pedagogical orientations and only then to concrete instructional strategies, the NIES model seeks to: (a) reduce susceptibility to neuromyths by making underlying mechanisms and assumptions explicit; (b) respect the level-of-analysis problem by integrating, rather than replacing, psychological and pedagogical constructs; and (c) narrow the translation gap by offering teachers a transparent reasoning framework rather than decontextualized "brain facts." Future empirical work, as outlined above, is therefore essential not only to test the effectiveness of Neuropedagogy, but also to examine whether this structured approach indeed mitigates some of the conceptual and practical problems identified in the critical educational neuroscience literature.

While the teacher reports and examples provide valuable *face validity* for the practicality and perceived usefulness of Neuropedagogy, they do not replace systematic empirical evaluation. The reflections are inherently subjective, based on self-report, and may be influenced by social desirability, selection bias, and the absence of controlled comparison conditions. At this stage, the teacher reflections serve primarily to generate hypotheses and to specify plausible mechanisms of impact (e.g., changes in lesson planning, in classroom climate, or in the interpretation of student behavior). Future research should build on these narrative insights by designing controlled studies that measure changes in teaching practices and student outcomes using validated instruments and, where feasible, neurocognitive indicators. In sum, the reflections are best viewed as qualitative, exploratory illustrations of implementation, whereas rigorous tests of the core Neuropedagogical claims will require prospective designs, comparison groups, and standardized outcome measures.

Future research directions

Future research may provide empirical support to the core theoretical claoms stated in this article. They can be detailed here in brief.

Learning is synaptic change – operationalization in classroom research

Future research in the core claim: Learning can be defined as dynamic reorganization of neural networks (synaptic change), and teaching as the deliberate facilitation of such change.

- Uses multilevel indicators of "synaptic change"
    - o Neural level: indirect markers of plasticity (e.g., changes in functional connectivity or task-related activation in networks associated with the targeted skill, pre–post intervention).
    - o Behavioral/cognitive level: durable changes in performance (accuracy, transfer, retention after delay) and not just immediate test scores.
- Designs NIES-based interventions vs. "business-as-usual" teaching
    - o Randomly assign classes/teachers to NIES-informed instruction versus standard instruction for a defined unit (e.g., fractions, reading comprehension).
    - o Pre–post measure: (a) learning gains; (b) delayed retention; (c) transfer to novel tasks.
    - o If resources permit, add a small neuroimaging/EEG subsample to examine whether greater behavioral learning in the NIES group is accompanied by more efficient or more integrated neural activation patterns in relevant networks.

This allows the synaptic-change definition to be tested via converging behavioral and neurobiological evidence, without requiring direct synaptic measurement.

"Teachers are neural architects" – testing impact of teacher knowledge and design

Core claim: Teachers who understand brain mechanisms and use the NIES process systematically will design instruction that more effectively shapes students' neural architecture and learning outcomes.

Future studies could:

- Measure teachers' neuropedagogical competence
    - o Develop a validated instrument that assesses:
        - ■ Conceptual understanding of key neural principles (plasticity, emotion–cognition integration, temporal integration, etc.).
        - ■ Ability to complete the four NIES stages for a given topic (from principle → brain attributes → pedagogical orientations → strategies).
- Relate this competence to classroom practice and student outcomes
    - o Use classroom observations and lesson-plan analyses to rate the extent to which teaching reflects NIES principles (e.g., spaced practice, emotionally engaged tasks, built-in consolidation time).
    - o Examine whether higher neuropedagogical competence predicts:
        - ■ Higher quality of instructional design (as rated by independent experts).
        - ■ Better student outcomes (achievement, retention, engagement, motivation).
- Intervention studies in teacher education
    - o Train one group of pre-service or in-service teachers in Neuropedagogy/NIES and compare to a control group receiving a generic "active learning".
    - o Follow both groups over a semester and compare changes in:
        - ■ Lesson design (NIES features).
        - ■ Student learning and engagement.

If the "neural architect" claim is correct, teacher understanding and use of NIES should explain unique variance in student outcomes beyond general pedagogical training.

Testing the NIES model as a four-stage process

Core claim: The specific sequence "neural principle → brain attributes → pedagogical orientations → instructional strategies" produces more coherent and effective teaching than ad-hoc "brain-based" recommendations.

Future research could:

- Compare full NIES vs. partial/unsystematic use of neuroscience
  - o Experimental design with three arms:
    - Full NIES training (all four stages).
    - "Brain facts" workshop (exposure to neuroscience without structured translation model).
    - Control PD (no neuroscience).
  - o Outcomes: quality of lesson plans (internal coherence from mechanism to strategy), fidelity of implementation, and student learning/engagement.
- Process-tracing studies
  - o Collect think-aloud protocols or design-journals from teachers using NIES.
  - o Analyze whether teachers explicitly reference neural principles and brain attributes when making instructional decisions, and whether such explicit referencing correlates with better observed classroom processes and student outcomes.

These designs test whether NIES adds something over and above "neuro-friendly rhetoric".

Empirical tests of the three exemplar neural principles

For each principle you present (emotion–cognition integration; "use it or lose it"; temporal integration), you can suggest concrete paradigms:

1. Emotion–cognition integration
   - o Compare units taught with systematic inclusion of emotionally engaging elements (narrative, personal relevance, play, curiosity-inducing challenges) to isomorphic units with neutral affect.
   - o Outcomes: learning, delayed retention, intrinsic motivation, physiological/arousal measures; ideally, also fMRI/EEG markers of coordinated activity between limbic and prefrontal regions in a subsample.
2. Use it or lose it (repetition and practice)
   - o Implement different spacing/distribution schedules (massed vs. spaced; with/without retrieval practice) framed explicitly as synaptic strengthening strategies.
   - o Assess long-term retention, transfer, and resistance to interference over weeks/months.
3. Time needed for neural integration

- Contrast compressed vs. temporally structured courses (same total hours) with built-in consolidation intervals and varied activities, as described in your examples.

Examine whether the temporally structured formats yield better deep understanding, transfer, and long-term recall, even if short-term test performance is similar.

Future research in Neuropedagogy may need to focus on several critical areas: (1) *Longitudinal studies*: Long-term follow-up research examining the sustained impact of NIES-based instruction on student achievement and cognitive development across diverse populations is essential for validating the approach's effectiveness. (2) *Professional development models*: Investigating the efficacy of various professional development approaches for integrating Neuropedagogical principles into teacher training programs will be crucial for successful widespread implementation. (3) *Comparative research*: Systematic comparison of Neuropedagogical approaches with traditional educational methods through controlled studies will strengthen the evidence base for the field. (4) *Cultural adaptation*: Examining how Neuropedagogical principles can be adapted to different educational systems and diverse cultural contexts will enhance the approach's global applicability. (5) *Neuroplasticity and individual differences*: Further research into how individual differences in neural plasticity affect learning outcomes and the customization of Neuropedagogical approaches accordingly.

Data availability statement

The datasets presented in this article are available on request. Requests to access the datasets should be directed to EG, grobgld@achva.ac.il.

Author contributions

IF: Writing – original draft, Writing – review & editing, Investigation. EG: Writing – original draft, Writing – review & editing, Investigation. AT-W: Writing – original draft, Writing – review & editing, Investigation.

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